

Stocks Harbour Nature Reserve Management Plan



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Government of Bermuda
Department of Environment and Natural Resources

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Executive Summary

The Stocks Harbour nature reserve is a 2.58 acre Government owned nature reserve managed by the Department of Environment and Natural Resources located in St. George's Parish at the eastern end of Bermuda. It is an engineered wetland that was originally created in 1943 to act as an infiltration basin to manage surface runoff water from the surrounding military airfield. The mangrove swamp that became subsequently established was via seed dispersal from trees growing in Stocks Harbour and Ferry Reach.

Land use of the nature reserve is controlled by both the Planning and Development Act (1974) and the Bermuda National Parks Act (1986). The surrounding areas are managed by YAO Baseball Bermuda, the Bermuda Airport Authority, and the Parks Department.

The swamp is a mix of red and black mangrove trees (*Rhizophora mangle* and *Avicennia germinans* respectively). Giant land crabs (*Cardisoma guanhumi*), sea lavender (*Limonium carolinianum*), and Bermuda killifish (*Fundulus relictus*) are also present within the swamp.

There is a fringing woodland of invasive vegetation, mostly Brazil pepper *Schinus terebinthifolia* and casuarina *Casuarina equisetifolia*, which is encroaching on the mangrove swamp. Sensitive removal of this vegetation is required for the benefit of the mangrove forest.

Proposed habitat enhancement activities include culling invasive plants and controlling invasive animals. The ultimate management goal is to have this nature reserve free of invasive species and replanted with native-dominated marshland vegetation. Creating signage and an engineered saltmarsh are additional proposed management activities.

Introduction

This management plan is written as per the requirement of Sections 11 and 12 of the Bermuda National Parks Act 1986.

This management plan shall serve as a guide for all activities related to the management and administration of the protected area so that the purposes for which it was established are met and maintained. The plan provides for the following:

- A) The long-term goals and purposes of the protected area and the problems that must be considered in order to achieve those goals and purposes;
- B) The boundaries and existing natural or historic features of—
 - i. the area as a whole;
 - ii. any classes or zones within the area;
 - iii. any peripheral areas which will require special attention in order to safeguard the purposes of the protected area;
- C) The management, administrative, scientific and support needs required to accomplish the goals and purposes of the protected area;
- D) The kinds of activities that will be regulated or prohibited within the protected area or within particular zones of the protected area;
- E) Such other information as may be necessary to satisfy the requirements of the Bermuda National Parks Act.

Location

The Stocks Harbour Nature Reserve is located on Southside Road in St. George's Parish between Stocks Harbour and the Bermuda International Airport.



Figure 1. Location of the Stocks Harbour Nature Reserve

Management

This site is listed as a Class 'A' Nature Reserve under the Bermuda National Parks Act (1986) and is managed by the Department of Environment and Natural Resources. The Department of Parks provides enforcement of the Act and the National Parks Commission provides advice to the Minister of Public Works responsible for the Act.

The Kindley Baseball Fields to the west of the nature reserve are managed by the sporting organization YAO Baseball Bermuda and the Bermuda Airport Authority maintains a 10 foot swath of land outside of the security fencing along the eastern and southern borders of the nature reserve. The Department of Parks manages the coastline north of the reserve, a portion of which is leased annually to the Bermuda R/C Oval Racing Club as a recreational site for remote controlled power boat racing.

Goals and Objectives

The management plan has been designed to:

- A) Safeguard and maintain plants and animals as well as geological, marine and other natural features, and fragile ecosystems in order to protect and preserve them;
- B) Provide for the use of the area in its natural state with a minimum of commercial and mechanized activity.

In order to effectively accomplish these objectives the management plan will:

- Conduct habitat and indigenous species enhancement activities
- Minimise all human use activities that negatively impact protected species
- Minimise the risk of introducing invasive species
- Conduct periodic control activities on non-indigenous species

Assessment

History

An ordnance survey map published by Arthur J. Savage (Lieutenant, Royal Engineers) in 1901 shows numerous islands which made up the community of St. David's in St. George's Parish (Fig. 2) prior to the construction of a military airfield during the mid-20th Century.



Figure 2. Overlay of the A.J. Savage ordnance survey map on a 2022 global satellite image of St. George's Parish. Image courtesy of Vantages of Bermuda.

Construction of the airfield, which began in 1941 and ended in 1943, involved levelling Longbird Island and infilling nearly 30 named and unnamed islands at the north of Castle Harbour, including the waterways between them, as well as approx. 20% of the harbour itself, to make a solid land-mass contiguous with St. David's Island and Cooper's Island. This added 750 acres (3 km²) to Bermuda and created a military airfield that was used by both the United States Airforce and the Royal Air Force until the end of the Second World War, after which the US Army Air Transport Command took control of the Kindley Airforce Base. The Bermuda Government took control of the Civil Aviation Terminal (later to be named the Bermuda International Airport) at the western end of the base in 1948. The American military relinquished its interests in 1995 and the entire 750 acre facility reverted to the Bermuda Government.

It has been suggested that this project represented the single greatest destruction of Bermuda's mangrove forests (Sterrer and Wingate, 1981). However, during the construction of the airfield a relatively large (ca. 1.5 acres) low-lying area was left unfilled between Longbird Island and St. David's Island (Figs. 3 & 4) to act as an infiltration basin to manage surface runoff water from the surrounding airfield. This basin was connected to Stocks Harbour via two culverts installed at sea level which allowed water to flow out of, and into, the basin. Fish, as well as red mangrove propagules and black mangrove seeds, subsequently entered on rising tides and colonized the

newly-created basin. The mangrove trees evidently thrived over the decades, largely due to the fact that this site is protected from erosion caused by hurricane wave damage.

The Stocks Harbour nature reserve was annexed into the National Parks System in 2017 as a Class 'A' protected area in order to manage and protect special natural features (e.g. the mangroves) and limit public access.



Figure 3. 1941 aerial of the Stocks Harbour area showing Longbird Island (A) and St. David's Island (B). The red star shows the location of the future Stocks Harbour nature reserve.



Figure 4. 2022 aerial of the Stocks Harbour area showing the location of the nature reserve.

Ecology

This nature reserve is 2.58 acres in area of which 1.54 acres (59.7%) is presently characterized as mangrove swamp, <0.01 acres (0.4%) is saltmarsh, and the remaining 1.03 acres (39.9%) is mostly woodland dominated by invasive vegetation (Fig. 5). The latter appears mostly as a narrow fringe encircling the entire swamp with two small thickets at the eastern and western ends.

The swamp comprises a mixture of red mangrove trees *Rhizophora mangle* and black mangrove trees *Avicennia germinans* with the oldest and largest trees located at the western end of the swamp. In 1997 the area of mangroves in this nature reserve was estimated to be 5679 m² which then increased to 6260 m² by 2019 (Dickinson, unpublished data). A relict saltmarsh is located at the eastern end with sea lavender *Limonium carolinianum* and glasswort *Salicornia perennis* growing in it. The saltmarsh has been decreasing in area over time through natural succession as the black mangrove trees slowly invade it (see Appendix). At high tides the swamp is inundated with sea water which comes from Stocks Harbour and enters via two culverts located in the NW corner of the reserve. The lag time is approx. 70 mins. At low tides the sea water drains out of the swamp and only remains in a few pockets of standing water. The land surrounding the swamp is two meters above sea level.



Figure 5. Stocks Harbour nature reserve habitat classification map

The fringing vegetation is dominated by invasive species, which are displacing the mangrove trees that are growing adjacent to them. The canopy forest is predominantly casuarina *Casuarina equisetifolia* and Brazil pepper trees *Schinus terebinthifolia*, with others species (e.g. fiddlewood *Citharexylum spinosum*, jumbie bean *Leucaena leucocephala*, Chinese fan palm *Livistonia chinensis*) scattered throughout. The understory is a mixture of invasive plants which typically grow in dense mats (e.g. asparagus fern *Asparagus densiflorus*, wedelia *Sphagneticola trilobata*, and cane grass *Panicum dichotomiflorum*) that exclude native understory vegetation.

There are presently a few places where native vegetation is growing in clumps around the mangrove swamp. Spiked marsh rush *Juncus maritimus* is most prominent at the eastern and southern edges, while saltmarsh ox-eye shrubs *Borrhchia frutescens* and buttonwood trees *Conocarpus erectus* are less abundant and more scattered. The swamp is inhabited by coffee bean snails *Melampus coffeus*, mangrove crabs *Goniopsis cruentata*, giant land crabs *Cardisoma guanhumi*, Bermuda killifish *Fundulus relictus*, and a few additional native fish species. There is a strong likelihood that American eels *Anguilla rostrata* also inhabit the Stocks Harbour mangrove swamp, but this needs to be confirmed.

Feral chickens *Gallus domesticus* are frequently seen in this nature reserve and have been observed roosting within the mangrove forest in past years. The surrounding woodland is inhabited by Jamaican anolis lizards *Anolis grahmi*, tropical house geckos *Hemidactylus mabouia*, and giant Asian centipedes *Scolopendra subspinipes*.

Indigenous wildlife

The following fauna are currently known to inhabit the mangrove swamp:

<i>Species name</i>	<i>Status</i>	
Bermuda killifish <i>Fundulus relictus</i>	Endemic	Level 2 listing on the Bermuda Protected Species Order (2016); Endangered.
Mullet <i>Mugil sp.</i>	Native	
Mojarra <i>Eucinostomus sp.</i>	Native	
Grey snapper <i>Lutjanus gresius</i>	Native	
Pinfish <i>Lagodon rhomboides</i>	Native	
Giant land crab <i>Cardisoma guanhumi</i>	Native	Level 1 listing on the Bermuda Protected Species Order (2016); Vulnerable.
Red mangrove crab <i>Goniopsis cruentata</i>	Native	
Coffee bean snail <i>Melampus coffeus</i>	Native	
Golden silk spider <i>Nephilla clavipes</i>	Native	

Table 1. Indigenous wildlife found within the Stocks Harbour nature reserve.

Juvenile mullet, pinfish, and grey snapper are found naturally occurring in the deeper permanent pools within the swamp. Killifish were deliberately introduced to the nature reserve in January 2023 (n=500) using stock originating from Lover’s Lake (*Fundulus relictus*) as per the recovery activities discussed in the Bermuda killifish recovery plan (Outerbridge, 2020). Killifish are endemic to Bermuda and there are currently two recognized species (Smith-Vaniz et al., 1999); *Fundulus relictus* is found in land-locked, brackish water ponds in St George’s Parish only while *F. bermudae* occurs in similar ponds scattered throughout the rest of Bermuda (Outerbridge, 2020). American eels are a very cryptic species and are difficult to see by casual observation. They are known to inhabit Bartram’s Pond in the Stoke’s Point nature reserve, some 650 meters to the NW, (Outerbridge, 2021) and it is likely that they are also in this reserve. Mangrove crabs and coffee bean snails can be observed upon the prop roots of the red mangrove trees, and giant land crabs inhabit burrows in the embankments surrounding the swamp. The latter species have limited abundance and a highly fragmented distribution on Bermuda (Copeland, 2020). Golden silk spiders are a seasonal inhabitant found within the canopy of the mangrove trees. A variety of bird species, both resident and migratory, can be seen at different times of the year in the wooded areas of the nature reserve, but none reside exclusively within the confines of the nature reserve. Examples of resident species include Bermuda white-eyed vireo, yellow crowned night heron, and gray catbird. More than a dozen migratory species have been recorded at this location during the winter months (e.g. Northern water thrush, palm warbler, black and white warbler, Northern parula, yellow-rumped warbler, common yellowthroat, yellow warbler, yellow throated warbler, pine warbler, blackpoll warbler, American pipit, blue grosbeak, bobolink (P. Watson, pers. comm.).

Both species of mangrove, killifish, giant land crabs, American eels, and Bermuda white-eyed vireos are all listed under the Protected Species Act (2003) and as such cannot be harassed, injured, disturbed, or killed. Furthermore, all non-pest birds are safeguarded under the Protection of Birds Act (1975).

Indigenous vegetation

The following flora are currently growing within the boundary of the nature reserve:

<i>Species name</i>	<i>Status</i>	<i>Importance</i>
Red mangrove <i>Rhizophora mangle</i>	Native	Mangrove trees provide a number of important ecological services (see below)
Black mangrove <i>Avicennia germinans</i>	Native	Mangrove trees provide a number of important ecological services (see below)
Buttonwood <i>Conocarpus erectus</i>	Native	A salt and wind tolerant coastal tree that can act as a wind break for mangroves.
Spiked marsh rush <i>Juncus maritimus</i>	Native	A salt and wind tolerant plant that provides a physical buffer between the swamp and the surrounding land.
Saltmarsh ox-eye <i>Borrchia frutescens</i>	Native	A salt and wind tolerant marsh plant that provides a physical buffer between the swamp and the surrounding land.

Sea lavender <i>Limonium carolinianum</i>	Native	An extremely rare saltmarsh plant found in only one location (the Stocks Harbour nature reserve).
Glasswort <i>Salicornia perennis</i>	Native	
Bermuda cedar <i>Juniperus bermudiana</i>	Endemic	Cultural value; Bermuda's national tree.
Bermudiana <i>Sisyrinchium bermudiana</i>	Endemic	Cultural value; Bermuda's national flower.
Jamaica dogwood <i>Dodonaea viscosa</i>	Native	
Baygrape <i>Coccoloba uvifera</i>	Native	
Turnera <i>Turnera ulmifolia</i>	Native	

Table 2. Indigenous vegetation found within the Stocks Harbour nature reserve.

Mapping surveys between 2019 and 2022 revealed that Bermuda has 50.8 acres of mangrove communities, of which 49% are coastal and 51% are found growing inland (Dickinson, unpublished data). Mangrove swamps have been described as being Bermuda's richest wetland resource (Thomas and Logan, 1992). They are tidal, form a connecting ecosystem between the land and the marine environment, and perform the following invaluable ecological services:

1. They stabilize the coastline by reducing erosion caused by storm surges, currents, waves and tides.
2. They protect water quality by removing nutrients and pollutants from storm-water runoff.
3. Mangrove peat absorbs water during heavy rains and storm surge, reducing the chances of coastal flooding.
4. They provide nursery habitat for many commercially important fish and shellfish (e.g. snappers and spiny lobsters), and they shelter a range of locally rare species.
5. They serve as nesting areas for some birds, such as green herons, and many different birds depend on mangroves for part of their seasonal migrations.
6. They act as carbon sinks by absorb carbon dioxide from the atmosphere. This service is becoming increasingly important as a means of combating climate change.

Some mangrove swamps that are currently land-locked on Bermuda have another important role to play, albeit one in the future; rising sea levels may one day turn swamps like the one in the Stocks Harbour nature reserve into ready-made coastal mangrove communities.

Red mangroves comprise the majority (64%) of Bermuda's mangrove communities, 24% have mixed red and black mangroves growing in them, and the remaining 12% are black mangroves only (Dickinson, unpublished data). Plants like the spiked marsh rush and saltmarsh ox-eye grow at the high tide mark and are important elements of this wetland because they create a physical barrier between the swamp and surrounding land. This barrier helps deter people, and some animals, from entering the mangrove forest as well as prevents some types of wind-blown trash from polluting the mangroves. Furthermore, these salt tolerant plants provide cover for some resident wildlife, such as the giant land crabs, thus making them less prone to disturbance.

Sea lavender has become a very rare plant on Bermuda and is only known to grow within the tiny relict salt marsh (approx. 76 m²) at this location. The saltmarsh habitat has never been well-developed on Bermuda and is disappearing due to habitat destruction caused by hurricanes, development, sea level rise, and natural succession by trees. It is unlikely that sea lavender was particularly common on Bermuda, even historically. In the 1918 publication ‘Flora of Bermuda’, Britton commented that sea lavender was found growing in a few places along the shores of Castle Harbour, but that was before the U.S. military began its dredging and land reclamation activities in 1941. Despite the fact that the marsh has been getting smaller over the past several decades it still has hundreds of sea lavender plants within it. Rising sea level combined with mangrove expansion will eventually cause the marsh to be subsumed into the surrounding mangrove swamp and, without active intervention, lead to the local extirpation of Bermuda’s sea lavender.

Risks

Non-indigenous wildlife

The following fauna are currently found within the boundary of the nature reserve:

<i>Species name</i>	<i>Status</i>	<i>Problem(s)</i>
Feral chicken <i>Gallus domesticus</i>	Invasive (pest)	Omnivorous and predatory scavengers which feed on a wide variety of plants and invertebrates.
Rats <i>Rattus norvegicus</i> & <i>Ratus rattus</i>	Invasive (pests)	Pose a risk to native nesting songbirds and have had a significant impact on the reproductive success of a number of indigenous plants.
Anole lizards <i>Anolis grahami</i> & <i>Anolis leachii</i>	Introduced & Naturalized	None known at this site
Tropical house gecko <i>Hemidactylus mabouia</i>	Introduced & Naturalized	Unknown at the moment
Giant Asian centipede <i>Scolopendra</i> <i>subspinipes</i>	Invasive (pest)	Unknown at the moment
Whistling frog <i>Eleutherodactylus</i> <i>johnstoni</i>	Introduced & Naturalized	None known at this site

Table 3. Non-indigenous wildlife found within the Stocks Harbour nature reserve.

Pest birds

Crows, kiskadees, house sparrows, starlings, and feral chickens are all deemed pests under the Protection of Birds Act (1975) and are resident on Bermuda year-round. Little can be done to keep the first four species out of the nature reserve, but the chickens can be routinely culled using air rifles and the sedative alpha-chloralose (see Pettit, 2013). Feral chickens are omnivorous and predatory scavengers which feed on a wide variety of plants and small invertebrates. It is not clear what impact they are having at this nature reserve but it would be prudent to control their numbers.

Rats

Eradication is not possible at this point in time, therefore continued monitoring and control will be required.

Anole lizards

There are four *Anolis* species presently established on Bermuda; the Jamaican anole *Anolis grahami*, the Antigua anole *Anolis leachii*, the Barbados anole *Anolis extremus*, and the Cuban anole *Anolis sagrei*. Only Jamaican and Antigua anoles have been observed in this nature reserve. The Cuban anole is a relatively recent arrival to Bermuda (Stroud et al. 2017) and the closest known sub-population of brown anoles is at the airport waste management facility (Outerbridge, personal observation). The Barbados anole is only known from Sandy's Parish (Macedonia et al. 2016). It is unclear what, if any, detrimental impacts anoles are having to the native biodiversity at this nature reserve; however control of these species is unfeasible at the moment.

Geckos

There are two non-native species of gecko which are established on Bermuda; the tropical house gecko *Hemidactylus mabouia* and the Mediterranean gecko *Hemidactylus turcicus*. Both species have been present since at least 2011 and currently have an island-wide distribution (Outerbridge and Massey, 2018). Numerous *H. mabouia* have been found on the trunks of large casuarina trees as well as under large items of trash within the dense thickets of Brazil pepper trees surrounding the mangrove swamp (Outerbridge, personal observation). It is not clear at the moment what ecological impacts these non-native geckos are having on the native biodiversity at this nature reserve. The removal of all ground cover objects from within this nature reserve will likely minimize the number of geckos that are capable of inhabiting it.

Non-indigenous vegetation

The following flora are currently growing within the boundary of the nature reserve:

<i>Species name</i>	<i>Status</i>	<i>Problem(s)</i>
Casuarina <i>Casuarina equisetifolia</i>	Invasive	Overcrowds mangroves and is prone to uprooting and falling down during high winds.
Brazil pepper <i>Schinus terebinthifolia</i>	Invasive	A fast growing plant that quickly forms a monoculture once established. Overcrowds mangroves. Aggressively self-seeds.
Fiddlewood <i>Citharexylum spinosum</i>	Invasive	A fast growing plant that can form a monoculture once established. The brittle branches easily break during storms.
Jumbie bean <i>Leucaena leucocephala</i>	Invasive	Forms a monoculture once established.
Indian laurel <i>Ficus microcarpa</i>	Invasive	Overcrowds mangroves.
Chinese fan palm <i>Livistonia chinensis</i>	Invasive	Fruit and seeds attract rats. Aggressively self-seeds.
Madagascar olive <i>Noronhia emarginata</i>	Invasive	Fruit and seeds attract rats. Aggressively self-seeds.

Surinam cherry <i>Eugenia uniflora</i>	Invasive	Forms a dense monoculture once established which excludes most other vegetation. Aggressively self-seeds.
Allspice <i>Pimenta diocia</i>	Invasive	Forms a monoculture once established which excludes most other vegetation.
White cedar <i>Tabebuia pallida</i>	Invasive	Known to aggressively self-seed.
Asparagus fern <i>Asparagus densiflorus</i>	Invasive	This fast growing understory plant can form dense monoculture stands which excludes native shrubs.
Cane grass <i>Panicum dichotomiflorum</i>	Invasive	A fast growing understory plant that quickly forms a very dense monoculture which excludes native shrubs.
Wedelia <i>Sphagneticola trilobata</i>	Invasive	A fast growing understory plant that quickly forms a very dense monoculture which excludes native shrubs.
Wild fennel <i>Foeniculum foeniculum</i>	Introduced & Naturalized	Forms a dense monoculture once established which can exclude native shrubs.
Oleander <i>Nerium oleander</i>	Introduced & Naturalized	None at this site
Pittosporum <i>Pittosporum spp.</i>	Introduced & Naturalized	None at this site
Common sage bush <i>Lantana involucrata</i>	Introduced & Naturalized	None at this site
French tamarisk <i>Tamarix gallica</i>	Introduced	None at this site
Boat lily <i>Tradescantia spathacea</i>	Introduced	An understory plant that can form a very dense monoculture which excludes native shrubs.

Table 4. Non-indigenous vegetation found within the Stocks Harbour nature reserve.

Casuarina, Brazil pepper, and fiddlewood trees are the most abundant non-native canopy species, forming dense thickets which outcompete slower-growing native plants and overcrowd mangroves growing beside them. Furthermore, casuarinas are prone to being uprooted during severe wind storms and falling into the swamp causing damage to the mangrove trees. Asparagus fern, wedelia, and cane grass are the most abundant non-native understory plants. These fast-growing species can also form dense thickets to the virtual exclusion of all else. The remaining species listed in Table 4 are currently found in limited abundance but efforts should be made to remove them before they become established at this location.

Garbage dumping

It is evident that the public have been disposing garbage in this nature reserve for decades. Trash can be found around the entire periphery of the reserve, especially along Southside Road where the border of the mangroves is littered with plastic bags, empty food containers, and hundreds of empty glass bottles. The terrestrial wooded areas contain abandoned pedal cycles, motor cycles, old plastic lawn furniture, vehicle batteries, broken television sets, and numerous articles of domestic garbage. There is also evidence that trucks have illegally dumped rubble, construction

material (i.e. broken tiles, metal pipes), and horticultural waste along the edges of the reserve. The latter can lead to the unwanted establishment of exotic and invasive plant species within the reserve and likely explains the presence of boat lily plants.

Traffic and the threat of road mortality to giant land crabs

The main public road currently serving St. David's Island is St. David's Road, which begins at the Swing Bridge roundabout in Stocks Harbour. The 2022 draft St. David's Community Plan; Background and Issues Report mentions the possibility of establishing the Southside Road as the main thoroughfare into St. David's and closing to traffic a half mile portion of St. David's Road in order to repurpose it as an extension to the Kindley Field National Park. This would mean that all traffic driving into and out of St. David's would pass within 20 feet of the mangrove swamp in the Nature Reserve. Not only would this likely lead to an increase in the amount of roadside litter but will very likely lead to crabs being struck and killed by motor vehicles during the night when they leave their underground burrows to look for food. Mitigation measures should be taken to prevent crabs from wandering into the public road, such as installing barrier fencing which has been effectively used in the USA to minimize road mortality of diamondback terrapins (e.g. corrugated tube barriers <https://wetlandsinstitute.org/conservation/terrapin-conservation/a-guide-for-building-terrapin-barriers-and-fences/>).

Environmental contamination

Local investigations of the health status of the wetland environment in Bermuda suggest that there are a range of contaminants which are having detrimental effects on the resident fauna (Fort et al., 2006a; 2006b; Bacon et al., 2012; Outerbridge et al., 2016). These contaminants include petroleum hydrocarbons (gasoline-range organics (TPH-GRO), diesel-range organics (TPH-DRO)), polycyclic aromatic hydrocarbons (PAH) and heavy metals. Entry into the wetlands comes through storm-water run-off from adjacent roadways, car parks and house drives, aerial deposition and leachate from nearby landfills and ground-water sources (Fort et al., 2006). Tissue residue analyses from a range of wildlife, including cane toads *Rhinella marina*, mosquitofish *Gambusia holbrooki*, killifish *Fundulus spp.*, red-eared sliders *Trachemys scripta elegans*, and diamondback terrapins *Malaclemys terrapin* collected from a variety of contaminated wetlands across Bermuda have shown that these contaminants are being accumulated and have induced developmental malformations, endocrine disruption, liver and gonad abnormalities plus immunological stress (Bacon et al., 2012). There are no road drains which empty directly into the Stocks Harbour nature reserve, however there is a large diameter drain located in the SE corner which channels surface runoff from the neighbouring airport aprons. The run-off is primarily rainwater but it would also include chemical spills and any suppressants used to control aviation fires within the catchment area, should such an event occur. An emergency response plan should be created to deal with these types of spillage, as has been done for crude oil in Bermuda's marine environment, in order to prevent (or minimize) entry into the wetland.

Climate change

Increased hurricane frequency and severity combined with rising sea levels threaten Bermuda's mangrove communities, particularly those in coastal or near coastal locations. Mangrove

communities are able to adapt to rising sea levels provided there is space to retreat landward, are sufficiently large and productive enough to general peat deposits, and are not prevented from retreat by walls, roads, or buildings. Unfortunately most of Bermuda's mangrove communities do not meet these criteria, therefore it is anticipated that as the effects of climate change continue to increase Bermuda's coastal mangrove forests will diminish. However, the 1.85 acres mangrove community found within the Stocks Harbour nature reserve is set back approx. 100 feet from the ocean, which affords it some protection. Furthermore, there is space to the east and west of the nature reserve for the mangrove trees to retreat in the face of rising sea level.

Management Activities

Prohibited activities

1. The full list of prohibited activities can be found under the Bermuda National Parks Regulations (1988) which can be viewed online (www.bermudalaws.bm). Examples of these activities include damaging any plants or animals within the reserve without authorization, leave any items of trash or refuse, go camping, take or abandon any animals (e.g. dogs, cats, chickens), light fires, or drive any vehicle through the reserve.

Ecological activities

Current:

1. Feral chickens are periodically culled in, and around, the nature reserve. This location is a known area where the public abandon unwanted chickens.

Proposed:

1. Continued feral chicken control using targeted shooting.
2. Invasive plant control. Manual removal of invasive plants using a combination of weed wrenches and felling with chainsaws. The cambium layer of fresh-cut stumps should be treated with herbicides to prevent re-growth. Diluted Garlon has proven effective in killing casuarina, Brazil pepper, jumbie bean, and Surinam cherry but it should not be used to treat trees growing in close proximity to mangroves because of the risk of accidental poisoning. Clearcast is a systemic herbicide which has been approved by the Florida Department of Environment for use on invasive vegetation growing adjacent to mangrove trees. Clearcast does not translocate through the soil and is practically nontoxic to birds, fish, and aquatic invertebrates. All cut vegetation should be chipped and spread on the ground to suppress invasive weed growth. Where feasible a backhoe excavator could be used to remove the largest Brazil pepper and casuarina tree stumps in lieu of applying herbicide.
3. Phased plantings of salt and wind tolerant coastal species such as saltmarsh ox-eye, spiked rush grass, and buttonwood using rooted (1-3 gallon container size) and transplanted specimens from other locations.

4. Undertake giant land crab surveys. A baseline survey is needed to establish the abundance and distribution of active burrows around the periphery of the swamp. This survey should be undertaken before the invasive vegetation is cleared from the nature reserve. A second survey should be done 12 months afterwards to determine how the crab colony responded to the removal of the vegetation. Periodic surveys should be performed every 5 years to monitor the survival of this colony.
5. Undertake American eel surveys to determine if this species inhabits the canals and deeper pools of the swamp.
6. Excavate the eastern end of the nature reserve to create a saltmarsh. An area approx. 1,400 m² has been identified (see Fig. 6) as a suitable place for an engineered saltmarsh. This small tract of land is 1-2 meters above sea level and already slopes gently to the swamp. Excavation should stop at the high water mark and the surrounding berms should be fashioned in a manner that allows giant land crabs to burrow into them. Creating a saltmarsh will provide new habitat for the sea lavender and the saline conditions will make it challenging for invasive terrestrial plants to re-colonize, thus alleviating the need for frequent maintenance.



Figure 6. Stocks Harbour nature reserve showing 1 meter elevation contours. The blue area shows the location of the proposed engineered saltmarsh.

7. Plant mangrove saplings in the spaces formerly occupied by invasive vegetation.
8. Regularly mow the grassy verges of the reserve.
9. Ensure that future invasive tree seedlings are removed in a timely manner. This can be accomplished by visiting the reserve annually. Saplings should be relatively easy to pull out of the ground using weed-wrenches.

Additional activities

1. Remove all trash from within the nature reserve.
2. Create and install interpretive signage for the public. This site could have four signs installed around the periphery of the swamp. The first could present general information about mangrove trees/forests and be installed on the north side adjacent to the road. The second could present information about saltmarshes in Bermuda and be installed at the east end, overlooking the relict saltmarsh. The third sign could be installed at the south west corner (landward edge) and discuss the transition from swamp to terrestrial communities, the impact that invasive vegetation has, as well as mangrove retreat due to increasing sea level rise. The fourth sign could be installed next to the culverts and describe the origin of the swamp and the importance of the culverts to the continued existence of the community.

Activities timetable

Activity	Timeline
Feral chicken control	Ongoing
Invasive plant control	Initial removal of all existing vegetation is expected to take 2-3 months; subsequent maintenance to be undertaken annually
Remove trash	1 week; subsequent maintenance to be undertaken prior to verge maintenance (i.e. every 3-4 months)
Undertake giant land crab surveys	Baseline and follow-up surveys are expected to take 1 day each; subsequent surveys (1 day each) to be undertaken every 5 years
Undertake American eel survey	1 week
Create graded salt marsh	Initial excavation and grading is expected to take 1 week
Plant native vegetation	As needed
Maintain verges	Every 3-4 months (grass cutting)
Design and create signage	1 month
Install signage	1 day

Table 5. Summary of management activities and associated timelines.

Bibliography

- Bacon, J.P., Outerbridge, M.E., Fent, G.M., Mathis, M., Fort, C.E., Fort, H.M. and Fort, D.J. 2012. Paradise lost? The effects of anthropogenic contaminants on wetland species in Bermuda. SETAC Europe. 23rd Annual Meeting. Glasgow, Scotland.
- Copeland, A. 2020. Management plan for the giant land crab *Cardisoma guanhumi* in Bermuda. Department of Environment and Natural Resources, Government of Bermuda. 36 pp.
- Dickinson, D.M. GIS Mapping Analyst, Department of Environment and Natural Resources, Government of Bermuda.
- Fort, D.J., Rogers, R.L. and Bacon, J.P. (2006a). Deformities in cane toad (*Bufo marinus*) populations in Bermuda: Part II. Progress towards characterization of chemical stressors. *Applied Herpetology* 3: 143-172.
- Fort, D.J., Rogers, R.L., Buzzard, B.O., Anderson, G.D. and Bacon, J.P. (2006b). Deformities in cane toad (*Bufo marinus*) populations in Bermuda: Part III. Microcosm-based exposure pathway assessment. *Applied Herpetology* 3:257-277.
- Macedonia, J.M., Clark, D.L., and McIntosh, A.P. 2016. Differential range expansion and habitat use among the naturalized *Anolis* lizards of Bermuda. *Herpetological Review* 47(4).
- Outerbridge, M.E. 2020. Recovery plan for the killifishes of Bermuda (*Fundulus bermudae* and *Fundulus relictus*). Department of Environment and Natural Resources, Government of Bermuda. 52 pp.
- Outerbridge, M.E. 2021. Management plan for the American eel *Anguilla rostrata* on Bermuda. Department of Environment and Natural Resources, Government of Bermuda. 39 pp.
- Outerbridge, M.E., O’Riordan, R., Fort, D.J., and Davenport, J. 2016. Eco-toxicological assessment of diamondback terrapin (*Malaclemys terrapin*) pond habitat, prey and eggs in Bermuda. *Marine Pollution Bulletin* 102:36–43.
- Outerbridge, M.E. and Massey, S.C.B. 2018. Two new additions to the terrestrial reptiles established on Bermuda, with notes on other species. *Herpetological Review* 49(3):508–510.
- Pettit, A. 2013. Feral chicken management plan for Bermuda. Department of Conservation Services, Government of Bermuda. 41 pp.
- Stroud, J.T., Giery, S.T., and Outerbridge, M.E. 2017. Establishment of *Anolis sagrei* on Bermuda represents a novel ecological threat to Critically Endangered Bermuda skinks (*Plestiodon longirostris*). *Biological Invasions*. DOI 10.1007/s10530-017-1389-1.
- Thomas, M. L. H. and Logan, A. (1992). A guide to the ecology of shoreline and shallow-water marine communities of Bermuda. Iowa. Wm. C. Brown Publishers. 345 pp.

Appendix



Figure 7. Photograph of the relict saltmarsh in 2003



Figure 8. Photograph of the relict saltmarsh in 2023



Figure 9. Aerial time series of the Stocks Harbour nature reserve from 1962 to 2012